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(54) **SYSTEM AND METHOD FOR REDUCING DARK CURRENT DRIFT IN A PHOTODIODE BASED ELECTRON DETECTOR**

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H01L 31/0216 (2014.01)
H01L 31/0224 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 31/105*** (2013.01); ***H01L 31/02164*** (2013.01); ***H01L 31/022416*** (2013.01)

(58) **Field of Classification Search**
CPC ... H01L 31/105; H01L 31/075; H01L 31/118; H01L 31/1185; H01L 29/868; G01T 1/24; G01T 1/244
See application file for complete search history.

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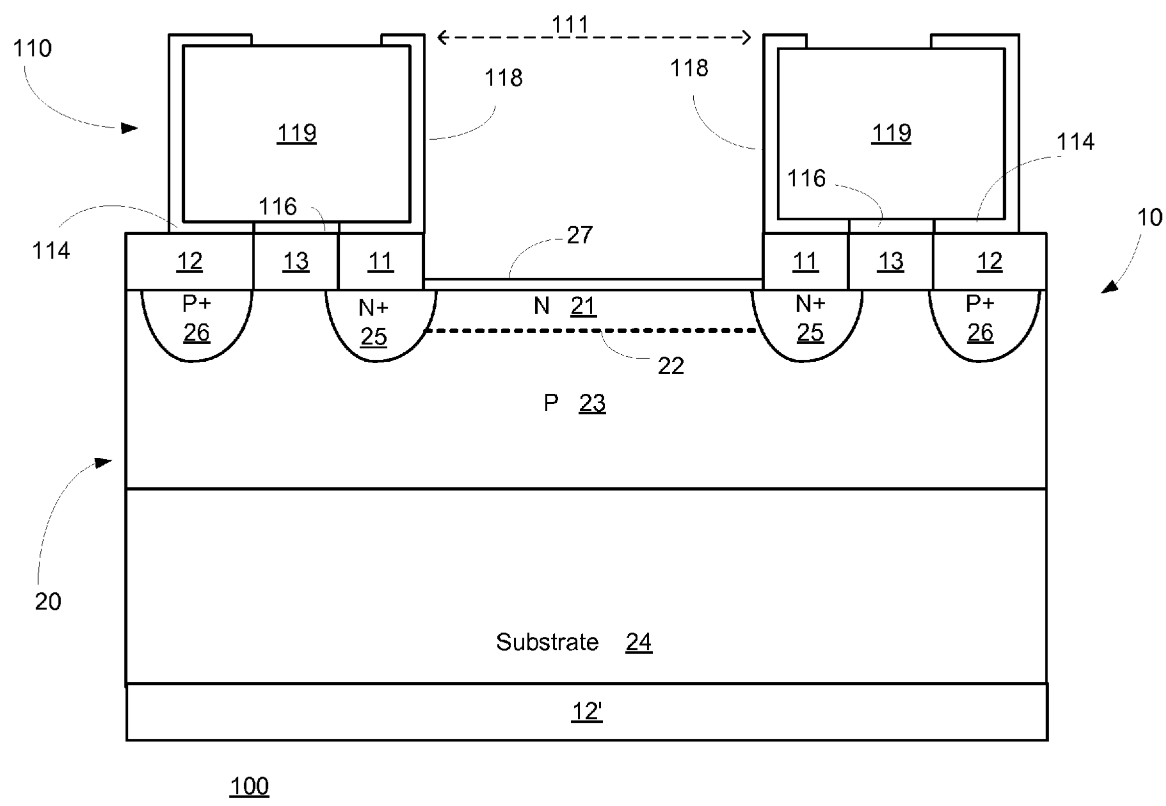
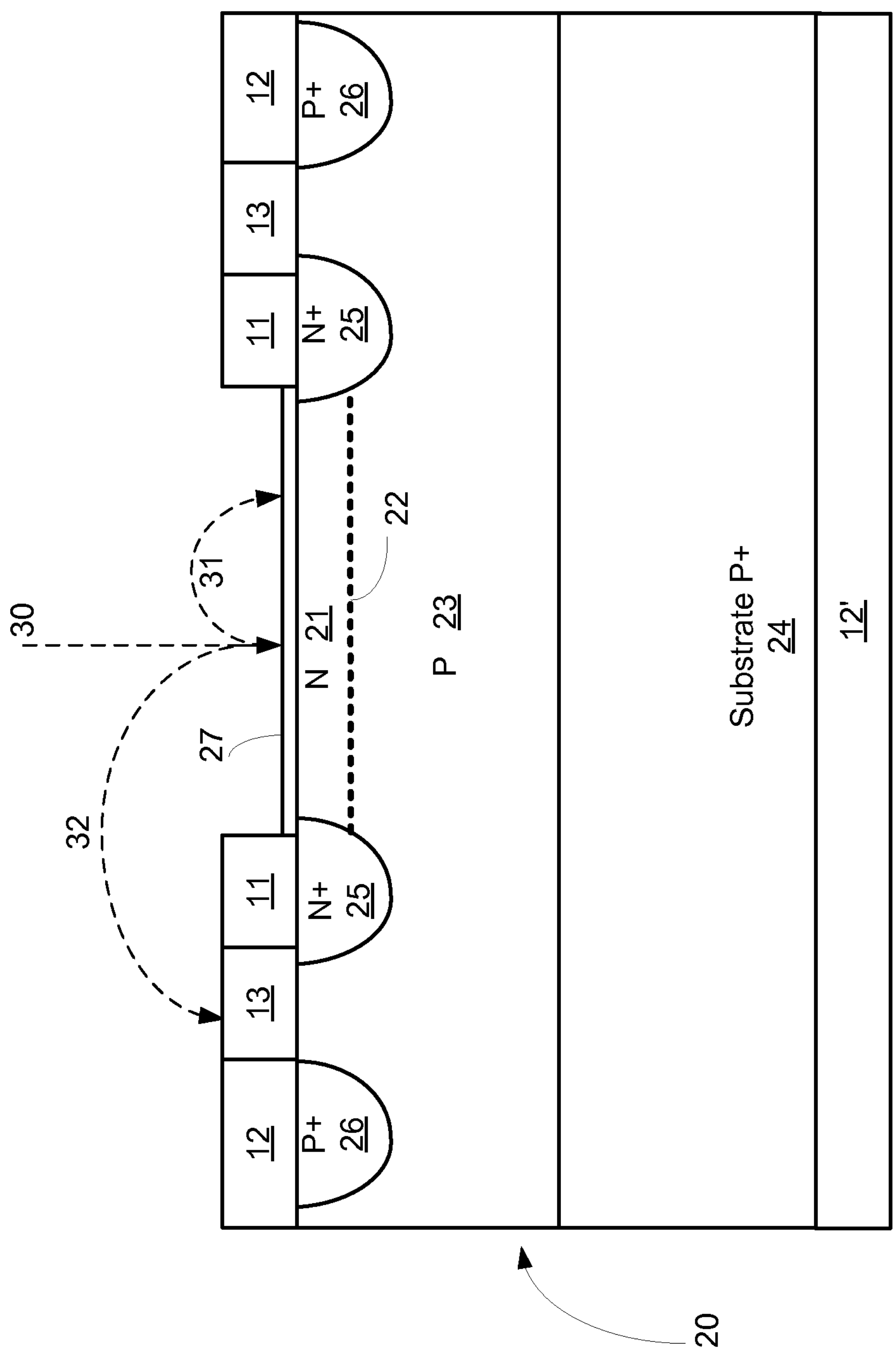
(57) **ABSTRACT**

A sensing element that may include (a) a PIN diode that may include an anode that is coupled to an anode contact; a cathode that is coupled to a cathode contact; a semiconductor portion that has a sensing region; and an insulator that is positioned between the cathode contact and the anode contact; and (b) a shielding element. The insulator, the cathode contact and the anode contact are positioned between the shielding element and the semiconductor portion. The shielding element is shaped and positioned to facilitate radiation to impinge onto the sensing region of the semiconductor portion while at least partially shielding the insulator from electrons that are emitted from the sensing region.

18 Claims, 5 Drawing Sheets





PRIOR ART
FIG. 1

10

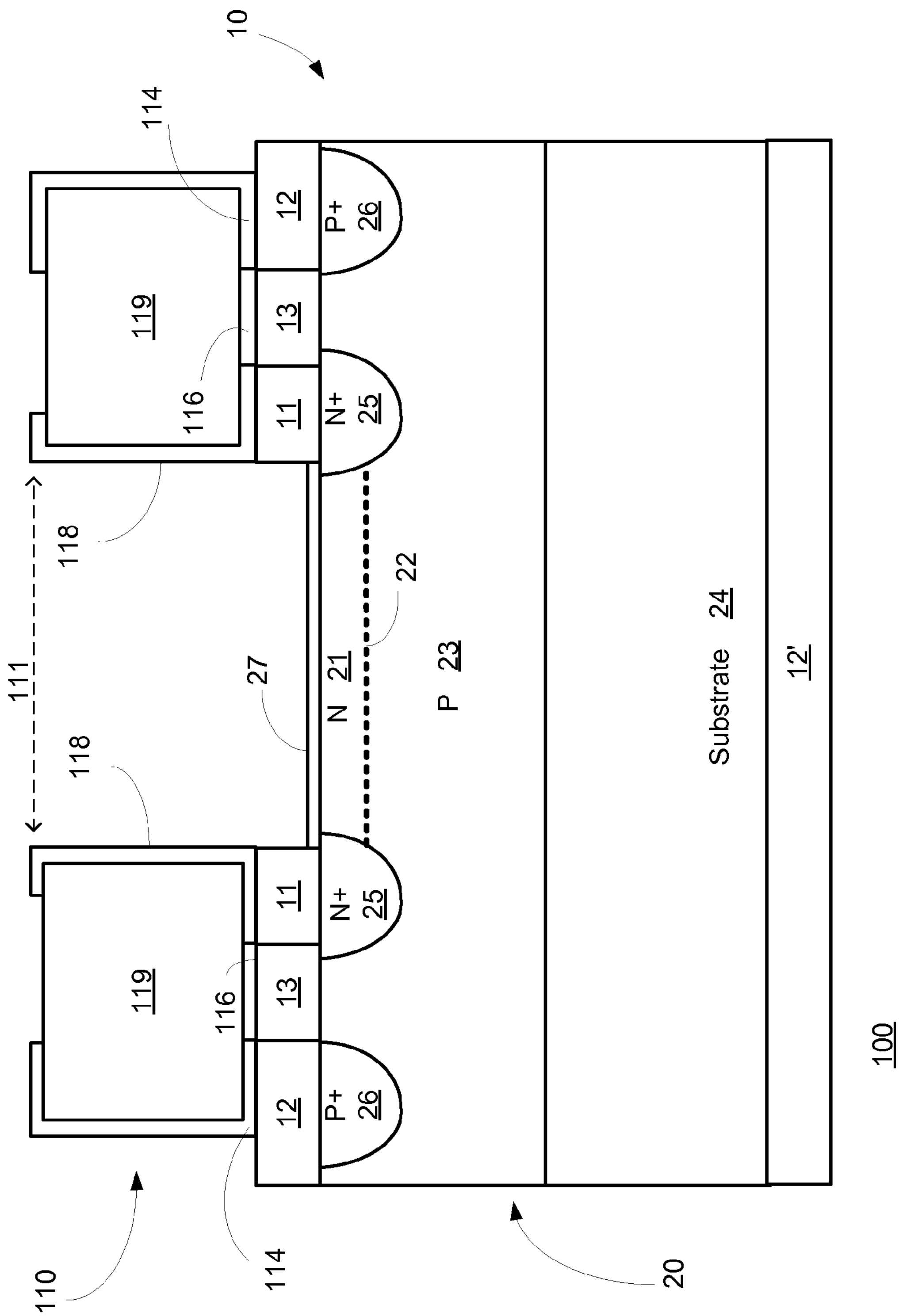

10
114
12
P+
26
13
119
116
11
N+
25
118
22
111
27
N 21
P 23
Substrate 24
12'
118
11
N+
25
119
116
13
12
P+
26
100
110
114
20

FIG. 2

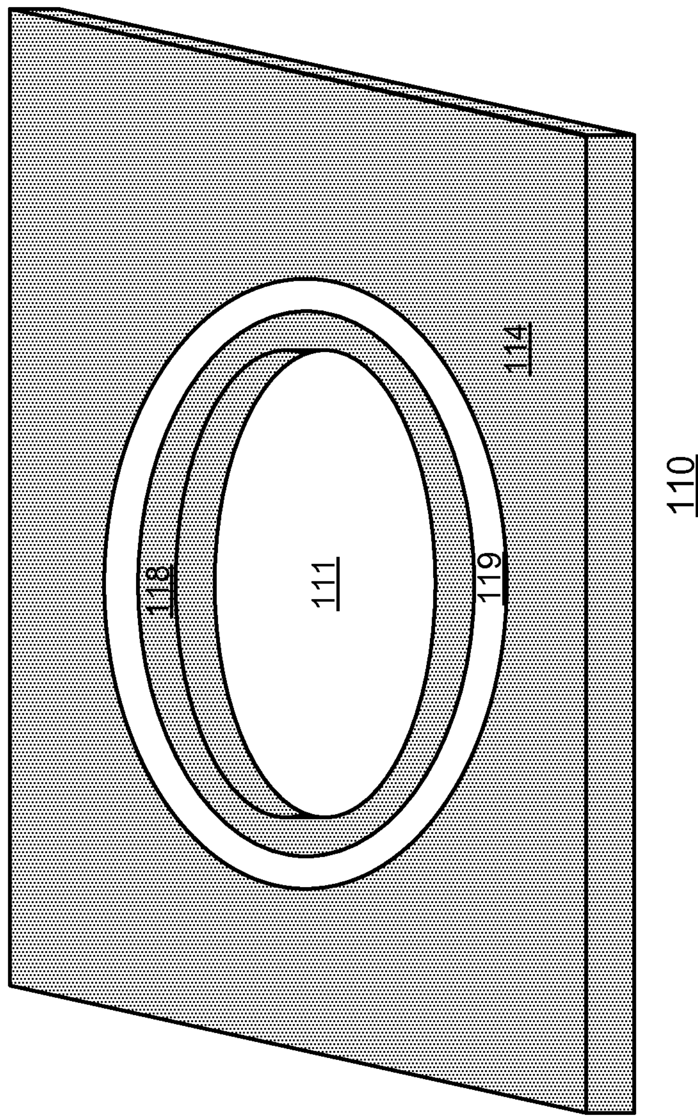


FIG. 3

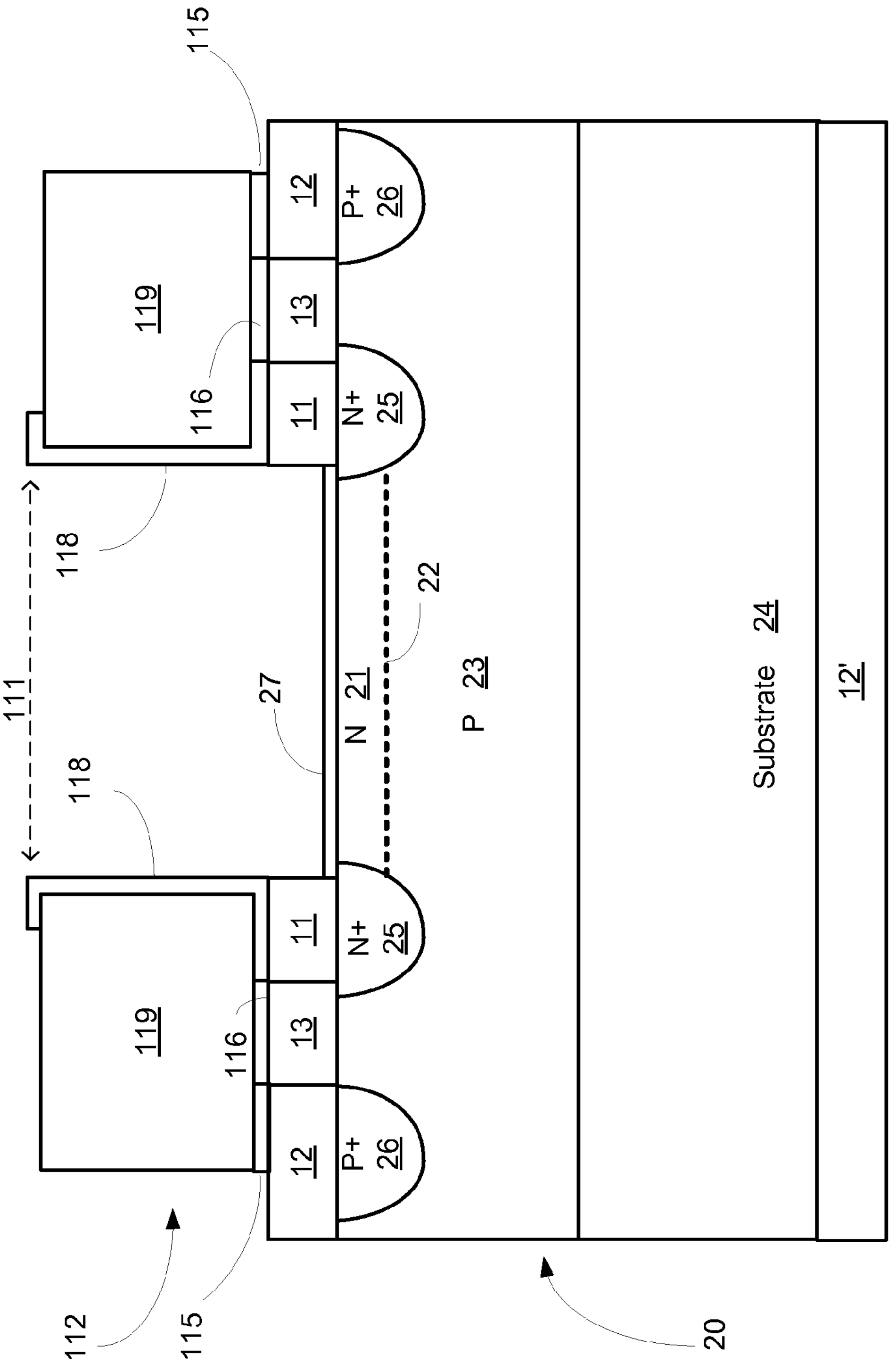

115
119
116
12
13
11
P+
26
N+
25
118
111
27
N 21
22
P 23
Substrate 24
12'
101
112
20

FIG. 4

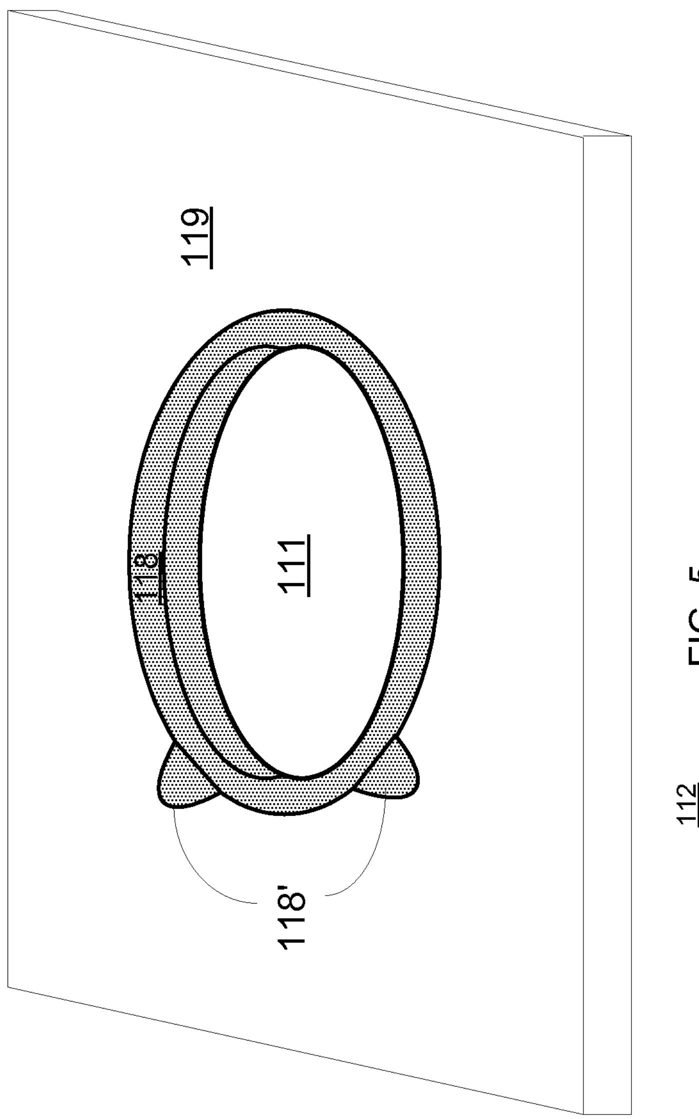


FIG. 5

SYSTEM AND METHOD FOR REDUCING DARK CURRENT DRIFT IN A PHOTODIODE BASED ELECTRON DETECTOR

BACKGROUND OF THE INVENTION

FIG. **1** illustrates a prior art PIN diode **10**. PIN diode **10** includes an anode that is connected to an upper anode contact **12** and to a lower anode contact **12'**, a cathode that is connected to a cathode contact **11**, a semiconductor portion **20** that has a sensing region and an insulator **13** that is arranged to insulate the cathode contact from the upper anode contact **12**. The insulator **13** and cathode contact **11** contact the upper surface of the semiconductor portion **20**.

Upper anode contact **12** contacts the upper surface of the semiconductor portion **20** while the lower anode contact **12'** contacts the lower surface of the semiconductor portion **20**—especially it contacts the lower surface of the substrate **24**.

The semiconductor portion **20** includes a negative doped (n-type) cathode layer **21**, an intrinsic layer **22**, a positive doped (p-type) anode layer **23**, a highly positive doped (P+ type) substrate **24**, a highly negative doped (N+ type) region **25** and a highly positive doped (P+ type) region **26**. FIG. **1** illustrates the n-type cathode layer **21** as being coated with a layer **27**.

An upper surface of the n-type layer **21** is positioned below the layer **27** and defines the upper surface of a sensing region of the PIN diode **10**. The sensing region may also include portions of the intrinsic layer **22** and the p-type layer **23**.

The cathode contact **11** and the upper anode contact **12** are coupled to the N+ type and P+ type regions **25** and **26** respectively.

The n-type layer **21** is the cathode and it is coupled to the cathode contact **11** via the N+ type region **25**.

The p-type layer **23** is the anode. The anode is coupled to the upper anode contact **12** via the P+ type region **26** and is coupled to the lower anode contact **12'** via substrate **24**. Insulator **13** is positioned between the upper anode contact **12** and cathode contact **11**. The N+ type region **25** may surround the n-type layer **21** and may also contact the intrinsic layer **22** and the p-type layer **23**.

When PIN diode **10** is used as electron detector it is aimed to detect primary electrons (PE) that propagate in a vacuumed environment towards the PIN diode. Arrow **30** illustrates a primary electron that impinges on layer **27**.

When the primary electron hits the active area (sensing region) of the PIN diode **10** it may create an electron\hole pair in the PIN junction formed by layers **21**, **22** and **23**.

The PIN diode **10** is biased by a reversed bias. Due to the applied reversed bias the electrons\holes pairs flow in the PIN junction and create a current signal through the PIN diode **10**.

An inevitable byproduct of the primary electron interaction with the PIN diode **10** is the emission of electrons such as secondary electrons and backscattered electrons from the PIN diode **10** to the vacuum. The emitted electrons can interact again with various areas of the PIN diode—including the sensing region (see arrow **31**) or with insulator **13** (see arrow **32**). The trajectory of the emitted electrons in the vacuumed environment is a function of the electric field in the vicinity of the front surface of the PIN diode, the energy and exit angle of the emitted electrons.

The impingement of the emitted electrons on the PIN diode can cause unwanted results.

If, the emitted electron impinges on the insulator **13** it may charge the insulator **13** positively or negatively (depends on the energy of the emitted electron) and can create undesired electric potential on the insulator **13**. This electric potential may remain even after the signal is ended, due to the very low charge mobility in insulator **13**. This electric potential may act as a gating potential on the PIN diode **10** and may open a new current channel between **25** and **26** in parallel to the PIN junction. This undesired conductance channel will create a new parasitic dark current which will be added to the signal that flows in the junction. The parasitic dark current can be extremely large and might change the output signal of the PIN diode **10** dramatically.

There is a growing need to provide a sensing element with lower dark current.

BRIEF SUMMARY OF THE INVENTION

According to various embodiments of the invention there may be provided a sensing element that may include a PIN diode that may include an anode that is coupled to an anode contact, a cathode that is coupled to a cathode contact, a semiconductor portion that has a sensing region, and an insulator that may be arranged to insulate the cathode contact from the anode contact; and a shielding element; wherein the insulator, the cathode contact and the anode contact are positioned between the shielding element and the semiconductor portion; wherein the shielding element may be shaped and positioned to facilitate radiation to impinge onto the sensing region of the semiconductor portion while at least partially shielding the insulator from electrons that are emitted from the sensing region.

The shielding element may have an aperture that is positioned above the sensing region.

The shielding element may include a cathode conductor that may be coupled to the cathode contact and an anode conductor that may be coupled to the anode contact.

Each of the cathode and anode conductors may have an end that may be formed at an exterior of the shielding element.

The cathode and anode conductors may be isolated from each other.

The cathode and anode conductors may be coupled to an insulating element of the shielding element.

The cathode and anode conductors may be coupled to exterior facets of the insulating element of the shielding element.

The sensing region may be circular and wherein the shielding element may have a circular symmetry.

The shielding element may be shaped and positioned to partially shield the insulator from the electrons that are emitted from the sensing region.

The shielding element may be shaped and positioned to completely shield the insulator from the electrons that are emitted from the sensing region.

The shielding element may include a ceramic plate that may be partially plated with metal anode and cathode conductors.

Any combinations of any of the components of any of the figures can be provided. Any combination of any of the mentioned above systems can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. **1** is a cross sectional view of a prior art sensing element;

FIG. **2** is a cross sectional view of a sensing element according to an embodiment of the invention;

FIG. **3** illustrates a shielding element according to an embodiment of the invention;

FIG. **4** is a cross sectional view of a sensing element according to an embodiment of the invention; and

FIG. **5** illustrates a shielding element according to an embodiment of the invention.

It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, and components have not been described in detail so as not to obscure the present invention.

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings.

The assignment of the same reference numbers to various components may indicate that these components are similar to each other.

FIG. **2** is a cross sectional view of a sensing element **100** according to an embodiment of the invention. FIG. **3** is an isometric view of a shielding element **110** according to an embodiment of the invention.

Sensing element **100** includes:

1. A PIN diode **10** that includes an anode that is coupled to an upper anode contact **12** and a lower anode contact **12'**, a cathode that is coupled to a cathode contact **11**, a semiconductor portion **20** that has a sensing region and an insulator **13** that is arranged to insulate the cathode contact from the anode contact.
2. Shielding element **110**.

The insulator **13**, the cathode contact **11** and the upper anode contact **12** are positioned between the shielding element **110** and the semiconductor portion **20**. If the sensing region of the PIN diode **10** faces upwards then the shielding element **110** can be viewed as belong located above the cathode contact **11**, the upper anode contact **12** and the insulator **13**.

The shielding element **110** is shaped and positioned to facilitate radiation to impinge onto the sensing region of the semiconductor portion **20** while at least partially shielding the insulator **13** from electrons that are emitted from the sensing region.

FIG. **2** illustrates the shielding element **110** as including (or as defining) an aperture **111** that is positioned above the sensing region.

In order to facilitate electrical coupling of an external conductor (external to the PIN diode) to the PIN diode **10** the shielding element may include a cathode conductor **118** that is coupled to the cathode contact **11** and an anode conductor **114** that is coupled to the upper anode contact **12**.

The cathode conductor **118** may include a lower plate, a vertical plate and an upper plate. The upper plate may be formed above the upper surface of the shielding element **110** to enable electrical coupling to an external conductor.

The anode conductor **114** may have a lower plate, an upper plate and a vertical plate. The upper plate may be formed at an exterior of the shielding element **110** to enable electrical coupling to an external conductor.

Each conductor of the cathode and anode conductors may have a different shape, more or less plates and the like.

The cathode and anode conductors **118** and **114** are isolated from each other. FIG. **2** illustrates a gap **116** formed between the cathode and anode conductors **114** and **118**. This gap **116** can remain empty or filled with isolating material. The gap **116** may be formed above insulator **13**.

The cathode and anode conductors **118** and **114** may be coupled to an insulating element **119** of the shielding element **110**.

FIG. **2** illustrates the cathode and anode conductors **114** and **118** as being coupled to exterior facets of the insulating element **119** of the shielding element **110**.

The cathode and anode conductors **114** and **118** may be smaller (for example may have a smaller width) than the insulating element **119** of the shielding element **110**.

The shielding element **110** may be thicker than the insulator **13**.

Higher shielding elements may inherently provide better shielding of the insulator **13** from the emitted electrons—as the emitted electrons must overcome a height barrier formed by the shielding element before landing on the insulating element **119** and charging it and even charge insulator **13**.

It is noted that even if an emitted electrode impinges on the upper surface of insulating element **110** and charges the insulating element—the effect on the PIN diode **10** is much smaller as the upper surface of the insulating element **119** is more distant from the semiconductor portion **20** than the upper surface of the insulator **13**.

The sensing region may be circular and the shielding element **110** may exhibit a circular symmetry.

The cathode and anode conductors **114** and **118** can be bonded or welded to the PIN diode **10**. The insulating element **119** can be made of Al_2O_3 alumina ceramics or other insulating materials and the cathode and anode conductors **114** and **118** can be made of gold or other conducting materials.

FIG. **3** illustrates a shielding element **110** that includes (a) a ring shaped cathode conductor **118** that defines a circular aperture **111** that corresponds to the shape and size of the sensing region and (b) an anode conductor **114** having an annular shaped upper portion that is spaced apart from the upper portion of the cathode electrode **118**. The radius of the aperture **111** can be about 2.5 millimeters, the height of the semiconductor portion **20** can be about 300 microns, the height of the native oxide layer **27** can be about 80 Angstroms, and the height of the shielding element **110** can be in range between 100 and 200 microns. Other dimensions can be provided.

FIG. **4** is a cross sectional view of a sensing element **101** according to an embodiment of the invention. FIG. **5** is a top view of a shielding element **112** according to an embodiment of the invention.

Sensing element **101** of FIG. **4** differs from sensing element **100** of FIG. **2** by having an anode conductor **115** that has only a lower portion—a plate shaped conductor that contacts the lower portion of the insulating element **119** while leaving the portions of the insulating element **119** above the anode exposed.

FIG. **5** illustrates a shielding element **112** that includes a ring shaped cathode conductor **118** that defines a circular aperture **111** that corresponds to the shape and size of the sensing region. The upper portion of the cathode conductor **118** may include structural elements such as "ears" **118'** that facilitate bonding of the cathode conductor **118** to the external circuit. These "ears" may have different shapes and sizes and may be absent from the cathode conductor **118**.

The radius of the aperture **111** can be about 2.5 millimeters, the height of the semiconductor portion **20** can be about 300 microns, the height of the layer **27** can be about 80 Angstroms, and the height of the shielding element **112** can be in range between 100 and 200 microns. Other dimensions can be provided.

In the foregoing specification, the invention has been described with reference to specific examples of embodiments of the invention. It will, however, be evident that various modifications and changes may be made therein without departing from the broader spirit and scope of the invention as set forth in the appended claims.

Any arrangement of components to achieve the same functionality is effectively "associated" such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as "associated with" each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being "operably connected," or "operably coupled," to each other to achieve the desired functionality.

Furthermore, those skilled in the art will recognize that boundaries between the above described operations merely illustrative. The multiple operations may be combined into a single operation, a single operation may be distributed in additional operations and operations may be executed at least partially overlapping in time. Moreover, alternative embodiments may include multiple instances of a particular operation, and the order of operations may be altered in various other embodiments.

However, other modifications, variations and alternatives are also possible. The specifications and drawings are, accordingly, to be regarded in an illustrative rather than in a restrictive sense.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word 'comprising' does not exclude the presence of other elements or steps then those listed in a claim. Furthermore, the terms "a" or "an," as used herein, are defined as one or more than one. Also, the use of introductory phrases such as "at least one" and "one or more" in the claims should not be construed to imply that the introduction of another claim element by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim element to inventions containing only one such element, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an." The same holds true for the use of definite articles. Unless stated otherwise, terms such as "first" and "second" are used to arbitrarily distinguish between the elements such terms describe. Thus, these terms are not necessarily intended to indicate temporal or other prioritization of such elements. The mere fact that certain measures are recited in mutually different claims does not indicate that a combination of these measures cannot be used to advantage.

While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those of ordinary skill in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

What is claimed is:

1. A sensing element, comprising:

a PIN diode having an anode coupled to an anode contact, a cathode coupled to a cathode contact, a semiconductor portion that has a sensing region, and an insulator positioned between the cathode contact and the anode contact; and

a shielding element comprising an anode conductor coupled to the anode contact and a cathode conductor coupled to the cathode contact, the anode conductor separated from the cathode conductor by an insulating element, wherein at least one of the anode conductor or the cathode conductor has a cross section with a substantially C-shape where a portion extends under a bottom of the insulating element, a portion extends along a side of the insulating element, and a portion extends over a top of the insulating element, and at least one of the portions is exposed along an exterior surface of the shielding element;

wherein the insulator, the cathode contact and the anode contact are positioned between the shielding element and the semiconductor portion, and the shielding element is shaped and positioned to facilitate radiation to impinge onto the sensing region of the semiconductor portion while at least partially shielding the insulator from electrons that are emitted from the sensing region.

2. The sensing element according to claim **1** wherein the shielding element has an aperture that is positioned above the sensing region.

3. The sensing element according to claim **1** wherein each of the cathode and anode conductors has an end that is formed at an exterior of the shielding element.

4. The sensing element according to claim **1** wherein the cathode and anode conductors are isolated from each other.

5. The sensing element according to claim **1** wherein the cathode and anode conductors are coupled to the insulating element of the shielding element.

6. The sensing element according to claim **1** wherein the cathode and anode conductors are coupled to exterior facets of the insulating element of the shielding element.

7. The sensing element according to claim **1** wherein the sensing region is circular and wherein the shielding element has a circular symmetry.

8. The sensing element according to claim **1** wherein the shielding element is shaped and positioned to partially shield the insulator from the electrons that are emitted from the sensing region.

9. The sensing element according to claim **1** wherein the shielding element is shaped and positioned to completely shield the insulator from the electrons that are emitted from the sensing region.

10. The sensing element according to claim **1** wherein the shielding element comprises a ceramic plate that is partially plated with metal the anode and cathode conductors.

11. A sensing element, comprising:

a PIN diode comprising a semiconductor portion having a cathode, an anode having an upper surface that defines an upper surface of a sensing region, an N+ region and a P+ region formed on a first side of a semiconductor substrate; a cathode contact formed on the semiconductor portion and coupled to the cathode through the N+

region; an upper anode contact formed on the semiconductor portion and coupled to anode through the P+ region; an insulator formed on the semiconductor portion between the cathode contact and the anode contact; and a lower anode contact on a second side of the semiconductor substrate opposite the first side; and

a shielding element comprising an insulating element having a first surface that defines an aperture positioned above the sensing region and a second surface opposite the first surface, a cathode conductor formed on at least a portion of the first surface and coupled to the cathode contact, and an anode conductor formed on at least a portion of the second surface and coupled to the upper anode contact, wherein the anode conductor is separated from the cathode conductor by the insulating element, and at least one of the anode conductor or the cathode conductor has a cross section with a substantially C-shape where a portion extends under a bottom of the insulating element, a portion extends along a side of the insulating element, and a portion extends over a top of the insulating element, and at least one of the portions is exposed along an exterior surface of the shielding element;

wherein the insulator, the cathode contact and the anode contact are positioned between the shielding element and the semiconductor portion, and the shielding element is shaped and positioned to facilitate radiation to impinge onto the sensing region of the semiconductor portion while at least partially shielding the insulator from electrons that are emitted from the sensing region.

12. The sensing element according to claim **11** wherein the anode conductor is electrically isolated from the cathode conductor by a gap positioned above the insulator.

13. The sensing element according to claim **12** wherein the gap comprises dielectric material.

14. The sensing element according to claim **11** wherein the sensing region is circular and the shielding element has a circular symmetry.

15. The sensing element according to claim **11** wherein the shielding element is thicker than the insulator.

16. The sensing element according to claim **11** wherein the cathode and anode contacts are bonded or welded to the N+ and P+ regions, respectively.

17. The sensing element according to claim **11** wherein the insulating element comprises Al_2O_3.

18. The sensing element according to claim **11** wherein the PIN diode further comprises an oxide layer formed over the sensing region.

* * * * *